Ecological Modelling 288 (2014) 203–212

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Exploring succession within aspen communities using a habitat-based modeling approach

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ARTICLE INFO

Article history:
Received 17 March 2014
Received in revised form 10 June 2014
Accepted 12 June 2014
Available online 2 July 2014

Keywords:
Conifer encroachment
Seral
Stable
Pure
GIS modeling
Functional types

ABSTRACT

Quaking aspen (*Populus tremuloides* Michx.) forest communities play a crucial ecological role across western North America. However, there is increasing evidence that these communities have diverging ecological roles across aspen's expansive range. Previous studies show evidence for both "seral" and "stable" aspen functional types. This leads us to believe that the pathway of these systems may not always lead to a climax conifer sere, but in many cases results in a stable community dominated by aspen. This study is an attempt to use a static model, based on large-scale environmental variables, to account for successional dynamics within aspen–conifer systems and predict distributions of aspen functional types across large landscapes. Environmental factors influencing aspen–conifer succession have been observed in past research but not fully explored. Our study methodologies and application of model results were specifically designed to aid land managers in identifying extent and function of aspen forest communities in order to plan restoration projects. Four study sites were chosen within Utah in order to capture the widest geographic variance. Photointerpretation of National Agriculture Imagery Program (NAIP) color infrared imagery was used to classify dominant forest cover at approximately 250 plots within each site. At each plot, variables were calculated and derived from DAYMET data, digital elevation models, and soil surveys and assessed for precision and ability to model forest type distributions. A generalized linear model was used to assess habitat overlap between aspen and conifer in order to explore successional dynamics and predict areas where stable aspen communities are likely to occur. Model results indicate an interaction between topographic position and moisture influence the probability of conifer encroachment but do not preclude conifers entirely. The highest probability for stable aspen communities occurs between 60 and 90 cm of total annual precipitation on topographic positions receiving greater than 4500 W h/m^2/d of solar radiation. Prediction-conditioned fallout-rates were used to partition the continuous model output into a "hard" classification. These results were applied in an overlay analysis with Southwest Regional Gap landcover data, indicating 19% of aspen forests across Utah are potentially stable functional types, whereas the remaining 81% are vulnerable to conifer encroachment.

1. Introduction

In western North America, quaking aspen (*Populus tremuloides* Michx.) occurs with conifer in mixed stands as well as in adjacent pure communities. Within this landscape aspen is often assumed to be seral to conifer species (Baker, 1918; Bartos et al., 1983). The successional trajectory of aspen to conifer is described as deterministic, where aspen requires disturbance or will eventually be replaced by encroaching conifer (Shepperd and Jones, 1985). However, many studies show evidence for not only a seral but a stable aspen community or functional type (Langenheim, 1962; Betters and Woods, 1981; Mueggler, 1988; Romme et al., 2000; Rogers et al., 2014a), describing such a community as one that persists free of conifers and is self-regenerating. This forest community has a disproportionately high ecological role to play within arid regions of the Intermountain West of the United States. High organic matter, nutrient rich soils, light, and water dynamics, specifically associated with these communities, provides an environment for a diverse assemblage of plants and wildlife as well as domestic livestock

Abbreviations: NAIP, National Agriculture Imagery Program; DAYMET, Daily Surface Weather and Climatological Summaries; SWReGAP, Southwest Regional Gap Analysis Project; UFRWG, Utah Forest Restoration Working Group.

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http://dx.doi.org/10.1016/j.ecolmodel.2014.06.010
0304-3800/

(Debyle and Winokur, 1985), in addition to other environmental services relating to water yield and ecosystem function (LaMalfa and Ryel, 2008). With aspen cover potentially decreasing (Bartos and Campbell, 1998; Rogers, 2002; Di Orio et al., 2005), there is an important need to classify stable and seral aspen sites to effectively plan aspen restoration projects (Rogers et al., 2014a).

While aspen is being encroached by conifer in many areas, there is intriguing evidence that it may be persisting and even expanding its distribution in others (Langenheim, 1962; Betters and Woods, 1981; Mueggler, 1988; Romme et al., 2000; Manier and Laven, 2002; Shepperd et al., 2006). These temporal studies suggest that at some sites aspen has remained in a persistent or stable state. Furthermore, despite light-limiting requirements of young aspen shoots, juvenile aspen have been shown to grow under the canopy of pure aspen stands and in gaps, enabling self-regeneration and suggesting a persistent or stable aspen community type (Kurzel et al., 2007). With an aim to develop a more detailed typology of "persistent" and "seral" stand structures, Kurzel et al. (2007) report that over 70% of the aspen-dominant stands they surveyed did not require stand-replacing disturbance events; alternatively, they regenerated through a variety of modes, with the majority (60%) regenerating "episodically" with a large pulse of suckering unrelated to course scale disturbance.

Though individual studies have documented stable aspen communities, environmental factors describing stable aspen habitat have not been thoroughly explored on a landscape scale. It is likely that successional processes in aspen–conifer systems are influenced by both broad and fine-scale mechanisms. Recent studies have uncovered broad patterns of seral and stable aspen types according to easily measured environmental variables (Rogers et al., 2014a). On the Owyhee Plateau in southwestern Idaho, Strand et al. (2009) found that 14% of their pure aspen plots seemed to occupy south-facing slopes above 1900 m. These aspen stands also showed characteristics of persistent stands being uneven-aged and self-regenerating. Over a 30-year period, Crawford et al. (1998, p.201) did not notice any appreciable conifer encroachment into pure aspen stands in a study performed in the montane and subalpine forests of Gunnison County, Colorado. Where conifer establishment did occur in aspen stands it was on the "cooler, moister north-facing slopes", where they have been observed to be seral to coniferous forests.

These studies suggest that environmental variables, such as topographic position, act as a surrogate for distinct conditions that may influence conifer encroachment. Therefore, we believe that using a static model approach, i.e. habitat-based, and relying on environmental variables to model distributions of aspen and conifer would provide an ecologically meaningful and landscape-level classification of seral and stable aspen communities. While fine-scale or site-specific mechanisms, such as grazing, fire regimes, soils, and genetics, likely play an important role in determining the successional dynamics of a particular aspen stand (Mittanck, 2012), such dynamics are difficult to quantify (Mueggler, 1988; Zimmerman et al., 2007). On the other hand static models with broader GIS-derived environmental variables may account for these fine-scale mechanisms while also providing key benefits such as cost-effectiveness, ability to apply across multiple spatial scales, as well consistency and repeatability.

Our primary objectives were twofold. First, using a generalized linear model approach and GIS-derived environmental variables, identify stable and seral aspen habitat. If this approach is successful, our second objective is to apply the model to larger landscapes. We believe there is great utility in landscape mapping of functional aspen types for the purpose of ecologically sound aspen restoration. Working at these large scales, we chose remote sensing and GIS applications as the most parsimonious way to proceed.

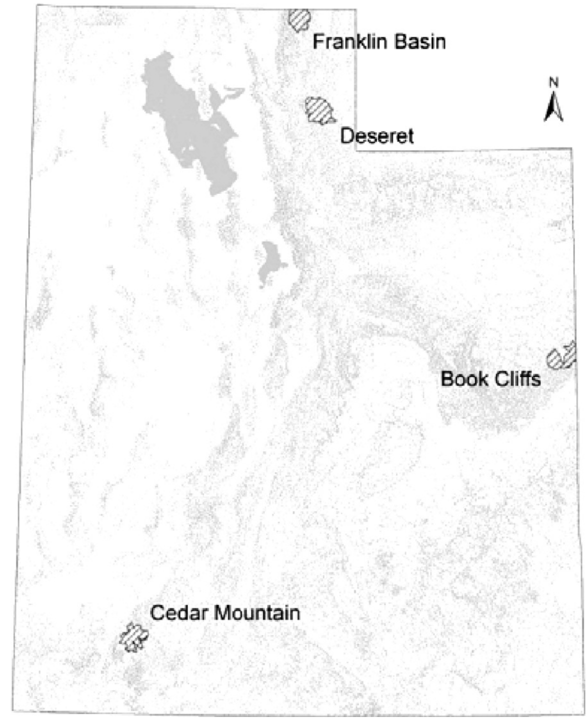

Fig. 1. The geographic context of the four study sites sampled. Site boundaries were delineated in order to capture entire site-scale distributions of aspen.

2. Methods

2.1. Study areas

Four sites within the state of Utah were chosen for this study (Fig. 1). At these sites prior aspen research had been conducted by researchers at Utah State University (Kusbach, 2010; Rogers et al., 2010). Much of the data from this prior research was adapted and used as "ground-reference" data for this current study. Although the selection of study sites was not random, we hoped to capture the majority of both the site-scale and regional-scale range of upland aspen by sampling within these climatically distinct study locations. The size of the study sites ranged from 18,000 to 33,100 ha with elevations ranging from 1770 to 3160 m. Tree species at these sites reflect the wide geographic and elevational range, and include: quaking aspen, Doug-fir (*Psuedotsuga menziesii* var. *glauca*), subalpine fir (*Abies lasiocarpa*), Englemann spruce (*Picea englemannii*), pinyon (*Pinus edulis*), juniper (*Juniperus scopulorum*), limber pine (*Pinus flexilis*), curl-leaf mountain mahogany (*Cercocarpus ledifolius* Nutt. ex Torr. & Gray), Gamble oak (*Quercus gambelii*), and Rocky Mountain maple (*Acer glabrum*). The topography, soils, precipitation, dominant plant communities, and historic and current land uses at each site were distinct and are discussed in detail by Mittanck (2012).

2.2. Sample design

In this study only the upland aspen stand type is considered, as defined by the Utah Forest Restoration Working Group (UFRWG) (O'Brien et al., 2010). This stand type includes primarily large contiguous stands that are not restricted to hydrologic features, such as riparian "stringers" and "snow-pocket" aspen types (Rogers et al., 2014a). We refined our target population for two reasons: (1) according to the UFRWG, the upland aspen type is one of the major ones "for which management or restoration decisions are repeatedly being made on the National Forests of Utah" (O'Brien et al.,